Estimates of Fish and Spill Passage Efficiency of Radio-Tagged Juvenile Steelhead and Yearling Chinook Salmon at John Day Dam, 1999

Final Report of Research

Prepared by:

Hal C. Hansel
John W. Beeman
Timothy D. Counihan
Brad D. Liedtke
Marc S. Novick
John M. Plumb

U.S. Geological Survey
Western Fisheries Research Center
Columbia River Research Laboratory
5501 A Cook-Underwood Road
Cook, Washington 98605

Submitted to:

U.S. Army Corps of Engineers
Portland District
Planning and Engineering Division
Environmental Resources Branch
Robert Duncan Plaza
333 S.W. 1st. Avenue
Portland, Oregon 97204-3495

Submitted:

May 18, 2000

Executive Summary

In 1999, the U.S. Army Corps of Engineers (COE) contracted with the U.S. Geological Survey to determine spill and fish passage efficiency at John Day Dam (JDA) using radio telemetry during 12- and 24-h spill treatments. The 12-h spill treatment consisted of 0% day spill from 0600-1859 h and 60% night spill from 1900-0559 h, whereas the 24-h spill treatment consisted of 30% spill from 0600-1859 h and 60% spill from 1900-0559 h. Spill treatments were alternated every three days for a total of four six-day blocks of study during the spring. Our specific objectives were to: 1) determine the proportion of radio-tagged juvenile steelhead (*Oncorhynchus mykiss*) and yearling chinook salmon (*O. tshawytscha*) passing through the spillway and powerhouse (both guided and unguided) at JDA during two different spill treatments, and 2) obtain information on the behavior of radio-tagged fish in the near-dam area prior to passage.

Dam Operations: Spill treatments were similar to those proposed during three of the four blocks of study. However, during these blocks, night spill averaged 45% instead 60%. During block four, spill remained at about 30% of the total dam discharge throughout the 24-h diel period to avoid high dissolved gas levels below the dam; data collected during this time were excluded from most analyses.

Number of Fish Released and Detected: From 7 May through 29 May, 479 juvenile steelhead and 469 yearling chinook salmon (spring migrants) were radio-tagged and released 23 km above John Day Dam. Among releases, 89 to 98% of both species were detected by telemetry receivers

at the dam; 94% of both species were detected overall.

Travel Time, Arrival Time, and Approach Pattern: Median travel times of juvenile steelhead and yearling chinook salmon from the Rock Creek release site to the JDA near-dam forebay were 27 and 17 h, respectively. Due to the time of the releases and the variable length of time it took individual fish to reach the dam, the hour of arrival of both species was widely dispersed throughout the diel period. Fifty-five percent of the juvenile steelhead and 44% of the yearling chinook salmon were first detected at the powerhouse, while the remaining fish were first detected at the spillway regardless of spill treatment.

Behavior in the Near-Dam Forebay: Median forebay residence times were influenced by hour of arrival, the percentage of total dam discharge being spilled at arrival, and the species. Median residence times of juvenile hatchery steelhead arriving at JDA during 0 or 30% day spill (11.4 and 11.3 h) were significantly longer than those of fish arriving during 45% night spill (0.3 to 0.5 h). This difference was due to passage delays of juvenile steelhead arriving during the 0 or 30% daytime spill conditions. The longer residence times associated with reduced day spill were related to fish size. Hatchery steelhead less than 201 mm in fork length (FL) had significantly shorter forebay residence times than fish greater than 200 mm FL (4.3 vs. 13.2 h), suggesting that wild juvenile steelhead (typically <200 mm) arriving at JDA during these spill conditions may pass the dam more quickly than the larger hatchery fish. Median forebay residence time of yearling chinook salmon arriving at JDA during 0% day spill (8.5 h) was significantly longer than the median residence times of fish arriving during either 30% day or 45% night spill (0.8 and <0.3 h, respectively). Both juvenile steelhead and yearling chinook salmon delaying at the dam, moved from one end of the dam to the other, and individuals commonly moved upriver at least as far as the receiver stations at the boat-restricted-zone line before returning downriver to the near-dam forebay. Some fish moved upriver from the dam repeatedly and the amount of time fish spent out of the near-dam area varied greatly.

General Route and Time of Passage: Increasing daytime spill from 0 to 30% increased yearling chinook salmon passage through the spillway over a 24-h period, but it did not significantly affect juvenile steelhead spillway passage. During the 00/45 treatment, 53% of the yearling chinook salmon passed through the spillway and 47% passed via the powerhouse. In contrast, during the 30/45 treatment, 66% of these fish passed through the spillway and 34% passed through the powerhouse. Forty-nine percent of the juvenile steelhead passed through the spillway and 51% passed through the powerhouse (treatments pooled).

The time of day that radio-tagged fish passed JDA was affected by species-specific travel times from the release site to the dam and species-specific responses to spill conditions at the time of arrival. Greater than 90% of the juvenile steelhead and yearling chinook salmon arriving during 45% night spill passed the dam under this test condition, indicating little passage delay. Seventy-five percent of the yearling chinook salmon arriving during 30% day spill also showed little passage delay and passed during the same spill condition. In contrast, 86 and 75% of the juvenile steelhead arriving at JDA during 0 and 30% day spill, respectively, and 65% of the yearling chinook salmon arriving during 0% day spill, delayed passage until evening. Because of these passage delays, greater than 79% of the juvenile steelhead passed at night regardless of spill treatment and 73% of the yearling chinook salmon arriving during the 00/45 treatment passed at night. Yearling chinook salmon passed about equally between night and day during the 30/45 treatment,.

Fish- and Spill-Passage Efficiencies: Neither juvenile steelhead or yearling chinook salmon FPE differed significantly between the 00/45 and 30/45 treatments. Estimates of juvenile steelhead FPE were 94% during the 00/45 treatment and 90% during the 30/45 treatment. Yearling chinook salmon estimates of FPE were 82 and 88% during the 00/45 and 30/45 treatments, respectively. Juvenile steelhead FPE was significantly greater than yearling chinook salmon FPE during the 00/45 treatment, but not during the 30/45 treatment.

Juvenile steelhead SPE did not significantly differ between treatments, but yearling chinook salmon SPE was significantly greater during the 30/45 treatment than the 00/45 treatment. Juvenile steelhead SPE was estimated to be 45 and 53% during the 00/45 and 30/45 treatments, respectively, whereas yearling chinook salmon SPE estimates were 53 and 66%. Estimates of SPE did not differ statistically between species during the 00/45 treatment, but the estimate of yearling chinook salmon SPE during the 30/45 treatment was significantly greater than the juvenile steelhead estimate of SPE.

Exclusion of the fourth block of data from these comparisons reduced our power to detect differences in FPE and SPE, but probably did not adversely affect our conclusions concerning differences in FPE because these differences were relatively small. Given a larger sample size of juvenile steelhead, however, we may have found a significant difference in SPE between treatments, as was the case for the yearling chinook salmon.

Effects of Species-Specific Passage Behavior on FPE and SPE: Potential differences in FPE estimates between spill treatments were reduced by species-specific responses to diel dam operations at the time of arrival. Differences in juvenile steelhead FPE estimates between treatments were minimized by the fact that fish arriving during 0 and 30% day spill generally delayed passage until evening. Because of this behavior, 87% of the juvenile steelhead passed the dam during 45% night spill. During this spill period, 51.2% of the juvenile steelhead passed through the spillway, 42.6% passed through the JBS, and 6.2% passed through the turbines. Few juvenile steelhead passed during 30% day spill (N=23), but the percentages of fish passing via the spillway and powerhouse were similar to those passing at night, suggesting that spill effectiveness was less during 45% night spill (1.1:1) than during 30% day spill (1.6:1). Fish guidance efficiency of juvenile steelhead that passed at night and during 0% daytime spill was higher than during 30% day spill (87.2, 85.0, and 58.3%, respectively).

Potential differences in yearling chinook salmon FPE estimates were also affected by passage delays during 0% day spill. Due to these delays, most fish arriving during the 00/45 treatment passed at night. Sixty-two percent of the fish passing during 45% night spill passed through the spillway, 22% passed through the JBS, and 16% passed through the turbines. During 30% day spill, 75% of the yearling chinook salmon arriving at JDA passed under this spill condition. Of the fish passing during the 30% spill, 73.9% passed through the spillway, 16.9% passed through the JBS, and 9.2% passed through the turbines. These data suggest FPE is higher for yearling chinook salmon that pass JDA during 30% day spill than fish that pass during 45% night spill (91 vs. 84%); due largely to increased spill effectiveness during the day (2.4 vs. 1.4). The tendency of yearling chinook salmon to pass readily through the spillway during 30% day spill resulted in significant differences in SPE between treatments. Fish guidance efficiency was higher during 0 and 30% day spill (81 and 65%, respectively) than during 45% night spill (57%).

Introduction

A Supplemental Biological Opinion issued by the National Marine Fisheries Service (NMFS) recommended that spill volumes at dams on the Columbia and Snake rivers be maximized to increase juvenile salmonid (*Oncorhynchus* spp.) survival without exceeding the current total dissolved gas (TDG) cap levels or other project-specific limitations (NMFS 1998). At John Day Dam (JDA), recent completion of spillway flow deflectors has increased the potential for greater spill volumes at this project while remaining under the TDG cap. Thus, the NMFS recommended that 24-h spill studies should be initiated at JDA in 1999 as a means of enhancing fish passage efficiency (NMFS 1998). At JDA, juvenile salmonids pass the dam via non-turbine routes through either the spillway, or the juvenile-fish-bypass system (JBS) after being diverted from turbine passage by submerged traveling screens.

Generally, a 1:1 relationship is assumed between the percentage of total fish that pass through the spillway and the percentage of total river flow passing through the spillway (Whitney et al. 1987). However, based on hydroacoustic evaluations, it is estimated that spill effectiveness is more efficient than the 1:1 ratio at John Day Dam and Whitney et al. (1997) calculated that spill volumes of 36 and 73% of total river flow were needed to achieve 80% fish passage efficiency for spring and summer migrants, respectively.

In 1999, the U.S. Army Corps of Engineers (COE) contracted with the U.S. Geological Survey to determine fish and spill passage efficiencies (FPE, SPE) at JDA using radio telemetry during 12- and 24-h spill treatments. The 12-h spill treatment consisted of 0% day spill from 0600-1859 h and 60% night spill from 1900-0559 h, whereas the 24-h spill treatment consisted of 30% spill from 0600-1859 h and 60% spill from 1900-0559 h. Each treatment was implemented for three consecutive days within a 6-day block and was repeated for a total of 4 study blocks in the spring. Our specific objectives were to: 1) determine the proportion of radio-tagged juvenile steelhead (*O. mykiss*) and yearling chinook salmon (*O. tshawytscha*) passing through the spillway and powerhouse (both guided and unguided) at JDA during the two spill treatments, and 2) obtain information on the behavior of radio-tagged fish in the near-dam area prior to passage.

Methods

Study Site

John Day Dam is located on the Columbia River at river km 347 (Figure 1). The dam consists of a single powerhouse of 16 turbine units, 4 skeleton bays, and a single spillway of 20 tainter gates. Both powerhouse and spillway are perpendicular to river flow. A navigation lock is located at the north end of the dam. Hourly powerhouse and spillway discharge data were obtained from the COE (1999).

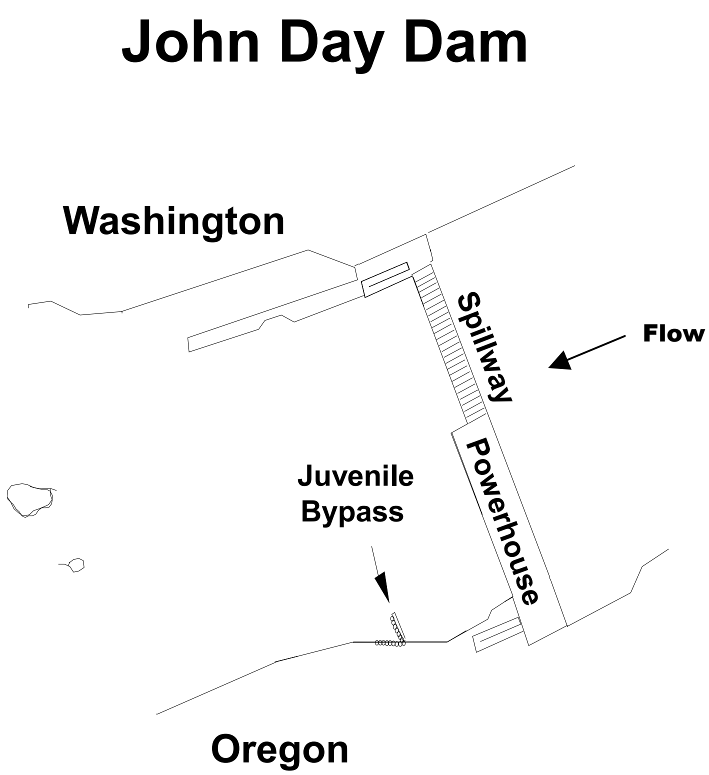

Figure 1. John Day Dam (river km 347) study site on the Columbia River. Juvenile steelhead and yearling chinook salmon were released 23 km upriver at Rock Creek, WA, in the north side of the river channel.

Radio Transmitters and Telemetry Receiving Equipment

Pulse-coded transmitters (Lotek Engineering, Newmarket, Ontario, Canada) were surgically implanted in juvenile steelhead and yearling chinook salmon allowing each individual fish to be recognized. Two sizes of these transmitters were used to accommodate the different sizes of the two species. Transmitters implanted in steelhead were 8.2 mm (diameter) x 18.9 mm and weighed 1.75 g in air, whereas transmitters implanted in yearling chinook salmon were 7.3 mm (diameter) x 18 mm and weighed 1.4 g in air.

Four-element Yagi (aerial) antennas were positioned along the periphery of the forebay to detect fish within about 100 m of the dam face, defined as the near-dam area. Each antenna monitored an area in front of a pair of turbine units or spill bays. These antennas were connected to Lotek SRX-400 receivers, which recorded the telemetry data, following the methods of Hensleigh et al. (1999). Additional aerial antennas were used to monitor the tailrace and area just upstream of the forebay boat-restricted zone. The SRX-400 receivers were configured to scan all antennas combined (master antenna) until a signal was received, and then cycle through individual aerial antennas (auxiliary antennas) to determine a precise location of the transmitter. Underwater antennas were used specifically to monitor radio-tagged juvenile salmonids in the juvenile fish bypass system and within about 10 m of the "B"-slot of each turbine unit and upstream of each spillway tainter gate. Up to seven underwater antennas were attached to a Lotek Digital Spectrum Processor in tandem with a SRX-400 receiver. The Digital Spectrum Processor allows simultaneous monitoring of all antennas and pulse-coded transmitters.

Fish Tagging, Handling, and Release

Juvenile steelhead and yearling chinook salmon to be implanted with radio transmitters were obtained from the juvenile collection and bypass facility operated by the NMFS at JDA. Fish to be implanted were transported to the release site at Rock Creek (river km 370) and generally held 24-36 h in river prior to tagging. Fish were considered suitable for tagging if they were free of injuries, severe descaling, external signs of gas bubble trauma, or other abnormalities. Transmitters were surgically implanted in both species following the methods of Adams et al. (1998).

Following tagging, fish were held in river for 20 to 24 hours in 114 L containers; three to four fish were held in each container. Following the holding period, the containers were checked for mortalities and then towed by boat out into the northern half of the river channel and released. These releases coincided with four 6-day blocks at JDA that consisted of each spill treatment for a period of three consecutive days. Approximately 240 fish per week were released (120 per spill treatment) with approximately equal numbers of juvenile steelhead and yearling chinook salmon in each release. In order to disperse the arrival of radio-tagged fish at JDA over the diel period, implanted fish were divided equally between day and night releases that occurred generally at 0800 and 2000 h.

We released a total of 479 juvenile steelhead and 469 yearling chinook salmon (Appendices A1 and A2). Juvenile steelhead had a mean fork length of 214 mm (range 117 to 287 mm) and mean weight of 86 g (range 29 to 227 g). Yearling chinook salmon had a mean fork length of 166 mm (range 123 to 246 mm) and a mean weight of 48 g (range 19 to 168 g).

Data Management and Analysis

Telemetry receivers were typically downloaded every other day and these data were imported into SAS (version 6.12; SAS Institute Inc., Cary, N.C., USA) for subsequent proofing and analyses. Proofing eliminated non-valid records including background noise, single records of a particular channel and code, records that were collected prior to the known release date and time, and records known to have been from fish that were consumed by avian predators. Generally, the minimum number of records required to consider detection of a radio-tagged fish valid was a combination of two master antenna detections and one auxiliary antenna detection, or three master antenna detections within about 1 to 2 minutes of each other.

The location and time an individual fish was first detected by receivers on the dam face was considered the route and time of entrance into the near-dam area. Similarly, the last detection of an individual fish on the receivers on the dam face was considered the route and time of passage through the dam. However, radio-tagged fish were often detected on multiple auxiliary antennas where zones of coverage overlapped, making data reduction necessary. Fish detected by more than one aerial auxiliary antenna within a two-minute period at the time of passage were assigned to a single passage location corresponding to the antenna where the highest strength signal was recorded, and all other records were excluded. A 2-minute interval was chosen because it approximately coincided with the upper boundary of time needed to complete a scan cycle if several fish were present at any given time. Manual tracking on the dams has verified that the last detection by the fixed-receiving stations is typically a good estimate of passage route (Sheer et al. 1997; Holmberg et al. 1998; Hensleigh et al. 1999). Juvenile steelhead and yearling chinook salmon approach and passage patterns among the various near-dam areas were compared between spill treatments using a Chi-square test. In this test and others throughout this report, results were considered statistically significant when $P \leq 0.05$.

Residence time in the near-dam area, defined as the amount of time between the first and last detections in the forebay, was calculated for each radio-tagged fish detected in the near-dam forebay area. These residence times are a minimum estimate of the actual time that radio-tagged fish spent in the near-dam area because fish may have been in the near-dam area for an unknown amount of time before their first detection and following their last detection. Median forebay residence times during a particular spill condition were compared statistically to those arriving under other spill conditions within and between species using Kruskal-Wallis tests. Within a particular day or night spill period, median residence times were also calculated for a series of time intervals to determine the effect of time of arrival on residence time within that period (e.g., 0% spill).

Fish passage efficiency was determined as the proportion of the total number of radio-tagged juvenile steelhead or yearling chinook salmon exiting the near-dam JDA forebay that passed by non-turbine routes (i.e., through the spillway and the JBS). Similarly, SPE was calculated as the proportion of the total number of radio-tagged juvenile steelhead or yearling chinook salmon that passed through the spillway. Ninety-five percent confidence limits for estimates of FPE and SPE were calculated using the Fisher and Yates relationship between the F distribution and the binomial distribution (Zar 1996). The FPE or SPE (proportion) for the two spill treatments were compared (e.g., HO: FPE_1=FPE_2) within and between species using the Fisher Exact Test (Zar 1996). The statistical power, or probability of rejecting the null hypothesis when it was in fact false, was derived using computations based on approximations to the Fisher Exact test (Zar 1996). Spill effectiveness is calculated as SPE divided by the proportion of total dam discharge being spilled and fish guidance efficiency is the proportion of fish passing through the powerhouse that are guided into the JBS. These two indices were used to help identify potential relations between spill treatments, FPE or SPE estimates, and juvenile salmonid passage behavior.

Results and Discussion

Dam Operations

Spill treatments were similar to those proposed in three of the four blocks (Table 1). During these blocks, night spill averaged 45% instead of 60% as proposed; but during the day, mean percent spill was near either 0 or 30% as planned in the first three blocks (Table 1). Throughout the remainder of this report, the two spill treatments will be referred to as 00/45 and 30/45 treatments, reflecting the actual day and night percent spills observed. During block four, spill remained at about 30% of the total dam discharge throughout the 24-h diel period to avoid high dissolved gas levels below the dam and data obtained during this time were excluded

Table 1. Mean hourly percentages of total discharge spilled and mean hourly total discharge (KCFS) at John Day Dam for four 6-day blocks, 7 May through 30 May, 1999. Proposed treatments consisted of one 3-day treatment of 30% day spill (0600-1859 h) and 60% night discharge (1900-0559 h) followed by a second 3-day treatment of no spill and 60% night discharge.

Block	Proposed spill treatment	Mean hourly percent Spill		Mean hourly total discharge	
		0600-1859	1900-0559	0600-1859	1900-0559
1	30/60	30.3	46.3	265.2	280.3
	00/60	4.7	47.7	270.1	254.1
2	30/60	30.0	44.9	254.1	269.1
	00/60	0.0	44.4	250.4	276.2
3	30/60	30.4	42.8	280.8	284.9
	00/60	0.2	45.6	252.9	263.9
4	30/60	30.3	31.3	337.4	365.9
	00/60	25.6	32.1	366.6	365.8

from most analyses. Mean hourly total discharge ranged from 253 thousand cubic feet per second (KCFS) to 367 KCFS during the study, but differed by no more than 30 KCFS between treatments within a block (Table 1).

Number of Fish Released and Detected

From 7 May through 29 May, we radio-tagged and released 479 juvenile steelhead and 469 yearling chinook salmon (spring migrants) 23 km above John Day Dam (Table 2). Among releases, receivers at the dam detected 89 to 98% of the juvenile steelhead and 89 to 97% of the yearling chinook salmon released (Table 2). Ninety-four percent of both species released were detected overall.

Table 2. Number of radio-tagged juvenile steelhead and yearling chinook salmon released 23 km above John Day Dam (JDA) and the percent of fish contacted by telemetry receivers at JDA, spring 1999. Paired release dates correspond to one of two spill treatments within four blocks.

	Juvenile steelhead		Yearling chinook		Total	
Release date	Number Released	Percent contacted	Number Released	Percent Contacted	Number Released	Percent contacted
05/07-05/08	59	98.3	57	89.5	116	94.0
05/09-05/11	58	91.4	60	93.3	118	92.4
05/12-05/14	57	96.5	60	96.7	117	96.6
05/15-05/17	46	91.3	60	96.7	106	94.3
05/18-05/20	59	93.2	59	96.6	118	94.9
05/21-05/23	57	89.5	56	91.1	113	90.3
05/24-05/26	74	97.3	65	93.9	139	95.7
05/27-05/29	69	95.7	52	96.2	121	95.9
Overall	479	94.4	469	94.9	948	94.2

Travel Time, Arrival Time, and Approach Pattern

Median travel time from the release site to the near-dam forebay of JDA was 27 h for juvenile steelhead and 17 h for yearling chinook salmon. Travel times for 90% of the juvenile steelhead and yearling chinook salmon ranged between 6 and 45 h and 5 and 29 h, respectively. Due to the time of the releases and the variable length of time it took individual fish to reach the dam, the hour of arrival at JDA for both species was widely dispersed throughout the diel period (Figure 2).

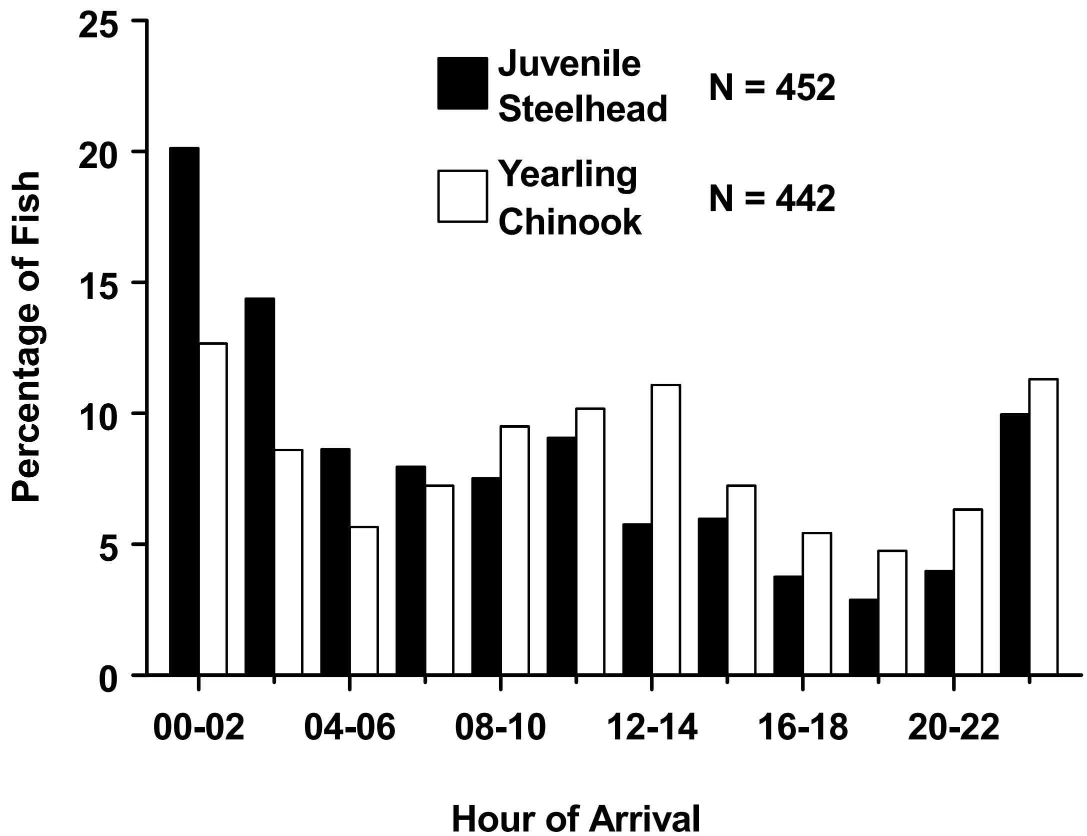

Figure 2. Diel distribution of radio-tagged juvenile steelhead and yearling chinook salmon hour of arrival among 2-h intervals at John Day Dam, spring 1999.

The distribution of both juvenile steelhead and yearling chinook salmon first detections between the spillway and powerhouse did not significantly differ between 00/45 and 30/45 treatments (Chi-Square test, P=0.72 and 0.08, respectively; Figure 3). However, the distribution of first detections among these near-dam areas did differ between species (spill treatments pooled, P=0.01). Overall, 55 and 44% of the radio-tagged juvenile steelhead and yearling chinook salmon were first detected at the powerhouse, respectively, with the remainder detected at the spillway (Figure 3).

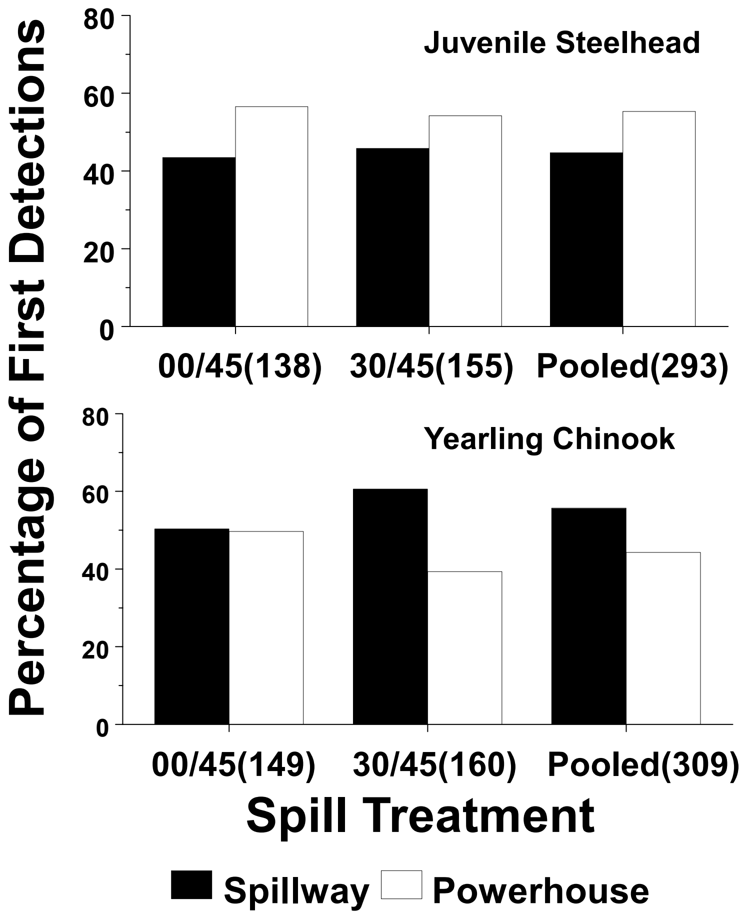

Figure 3. Distribution of juvenile steelhead and yearling chinook salmon first detections between spillway and powerhouse receivers in the John Day Dam near-dam forebay during two spill treatments, spring 1999. Spill treatments: 00/45=0% day and 45% night spill; 30/45=30% day and 45% night spill. Sample sizes are in parentheses.

Behavior in the Near-Dam Forebay

Forebay residence time was influenced by fish arrival time, percent spill at arrival, and species (Table 3). Median residence times of juvenile steelhead arriving during 0 or 30% day spill were significantly longer (11.4 and 11.3 h, respectively) than those of fish arriving during

45% night spill during the 00/45 and 30/45 treatments (0.3 and 0.5 h; Kruskal-Wallis tests, $P<0.001$).

Differences in median residence times between juvenile steelhead arriving during 0 and 30% day spill were not significant (Kruskal-Wallis test, $P=0.60$) and during both spill levels, median residence times became progressively less as a fishes arrival time approached the 1900 h change to the 45% night spill. Juvenile steelhead arriving between 0600 and 1059, after the 0600

Table 3. Median forebay residence times (h) of radio-tagged juvenile steelhead and yearling chinook salmon by time of arrival and spill treatment at John Day Dam, spring 1999. Sample sizes are shown in parentheses.

		Juvenile steelhead		Yearling chinook	
Time of	Spill	Spill treatment		Spill treatment	
Arrival	period	00/45	30/45	00/45	30/45
0600-1059	Day	14.5 (29)	13.4 (31)	10.6 (27)	0.6 (30)
1100-1459	Day	11.1 (21)	11.8 (16)	7.6 (35)	1.8 (29)
1500-1859	Day	7.3 (13)	6.9 (14)	4.8 (10)	0.6 (16)
Pooled	Day	11.4 (63)	11.3 (61)	8.5 (72)	0.8 (75)
1900-2259	Night	0.2 (14)	0.6 (16)	0.5 (19)	1.3 (19)
2300-0259	Night	0.4 (36)	0.4 (44)	0.2 (35)	0.1 (43)
0300-0559	Night	0.3 (14)	0.6 (27)	0.1 (15)	0.4 (15)
Pooled	Night	0.3 (64)	0.5 (87)	0.2 (69)	0.3 (77)
Overall		4.4 (127)	1.7 (148)	1.4 (141)	0.5 (152)

change to 0 or 30% day spill, had median residence times of 14.5 and 13.4 h; fish arriving between 1100 and 1459 h had residence times of 11.1 and 11.8 h, and; fish arriving between 1500 and 1859 h had median residence times of 7.3 and 6.9 h (Table 3). These results indicate that a large proportion of the juvenile steelhead arriving during the day waited until night spill conditions to pass. In contrast, juvenile steelhead arriving during 45% night spill generally passed relatively quickly with median residence times #0.7 h regardless of the hour of their arrival. Differences in median residence times of fish arriving during 45% night spill were not significant between treatments (Kruskal-Wallis test, P=0.40; Table 3).

The residence times of radio-tagged hatchery steelhead arriving during 30% day spill were related to fish size. Fish less than 201 mm in fork length (FL) had significantly shorter forebay residence times than fish greater than 200 mm FL (4.3 vs. 13.2 h; P=0.003). Although we did not tag wild fish, these data suggest that wild juvenile steelhead (typically <200mm) arriving at JDA during similar spill conditions may also pass the dam more quickly than the larger hatchery fish. Fish length did not significantly affect the residence times of juvenile steelhead arriving during no spill (P=0.62) or 45% night spill conditions (P>0.51).

Yearling chinook salmon arriving in the forebay during no spill tended to delay passage until night like juvenile steelhead, but they had a significantly shorter median residence time than the steelhead (8.5 vs. 11.4 h; Kruskal-Wallis test, P=0.003). Yearling chinook salmon arriving in the near-dam forebay between 0600 and 1059 h when there was no spill had a median residence time of 10.6 h; fish arriving between 1100 and 1459 h had a median residence time of 7.6 h; and fish arriving between 1500 and 1859 h had a median residence time of 4.8 h. Yearling chinook salmon arriving during 30% day spill passed relatively quickly with a significantly shorter pooled median residence time (0.8 h) than either yearling chinook salmon or juvenile steelhead (8.5 and 11.4 h) arriving during no spill (Kruskal-Wallis test, P<0.001). Median residence times of yearling chinook salmon arriving during 45% night spill during 00/45 and 30/45 treatments (0.2 and 0.3 h, respectively) were significantly less than those of fish arriving during corresponding day spill levels (P<0.003), but did not differ from those of juvenile steelhead (P=0.31 and 0.20, respectively).

Both juvenile steelhead and yearling chinook salmon delaying at the dam moved from one end of the dam to the other and individuals commonly moved upriver at least as far as the receiver stations at the boat-restricted-zone line before returning downriver to the near-dam forebay. Some fish moved upriver from the dam repeatedly and the amount of time fish spent out of the near-dam area varied greatly.

General Route and Time of Passage

The distribution of juvenile steelhead passage through the spillway and powerhouse did not differ significantly between the 00/45 and 30/45 treatments (Figure 4; blocks 1-3 pooled; Chi-square Test, P=0.20), but yearling chinook salmon passage did (P=0.02). Approximately 45 and 53% of the juvenile steelhead passed through the spillway during the 00/45 and 30/45 spill treatments, respectively, while the remaining fish passed through the powerhouse. Fifty-three and 66% of the yearling chinook salmon passed through the spillway during 00/45 and 30/45 treatments, respectively, while 47 and 34% of the fish passed through the powerhouse.

The time of day that radio-tagged fish passed JDA was affected by species-specific travel times from the release site to the dam and species-specific responses to spill conditions at the time of their arrival (Figure 5). Ninety-two percent of the juvenile steelhead arriving during 45% night spill passed under this spill condition, indicating little passage delay. In contrast, 86 and 75% of the juvenile steelhead arriving at the dam during 0 and 30% day spill, respectively, delayed passage until evening. Because of these passage delays associated with daytime spills, more than 79% of the juvenile steelhead passed at night regardless of the spill treatment.

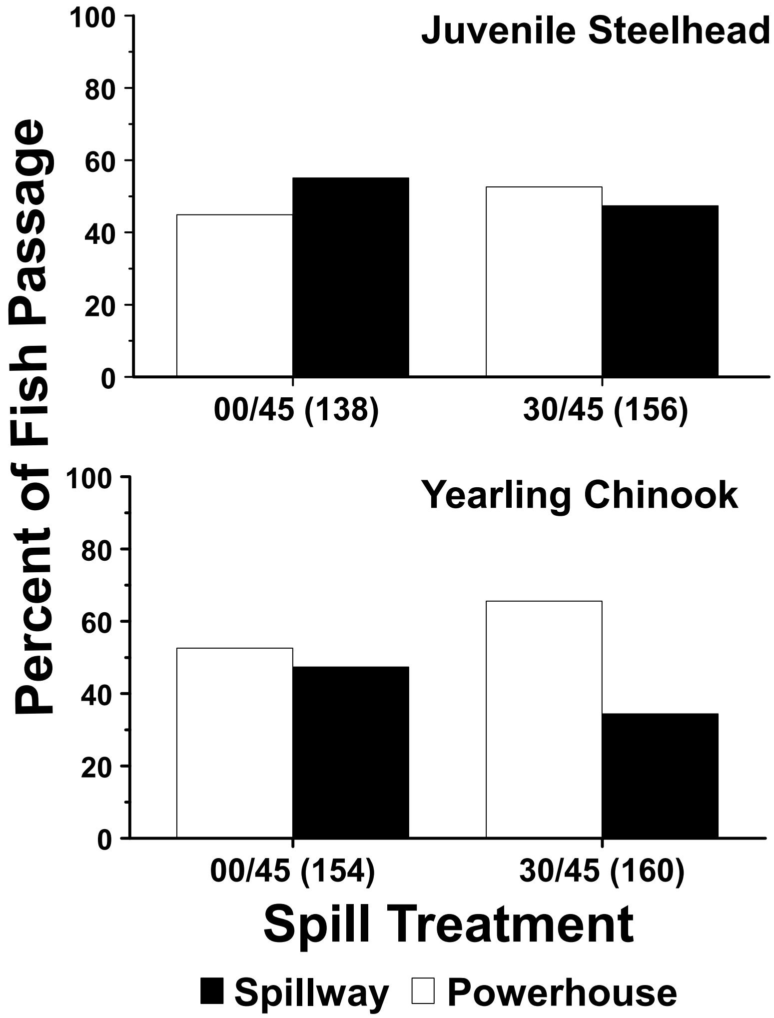

Figure 4. Percentage of juvenile steelhead and yearling chinook salmon passing John Day Dam through the spillway and powerhouse for two spill treatments, spring 1999. Spill treatment: 00/45=0% day and 45% night spill; 30/45=30% day and 45% night discharge. Sample sizes are shown in parentheses.

More yearling chinook salmon passed at night than in the day during the 00/45 and 30/45 treatments (73 and 57%, respectively; Figure 5), but night passage was not as predominant as it was for juvenile steelhead because proportionately fewer yearling chinook salmon delayed passage during the day spill. Ninety-five and 75% of the yearling chinook arriving at JDA during 45% night and 30% day spill, respectively, passed during the same spill condition. In contrast, 65% of the fish arriving during 0% spill delayed dam passage until the 45% night spill.

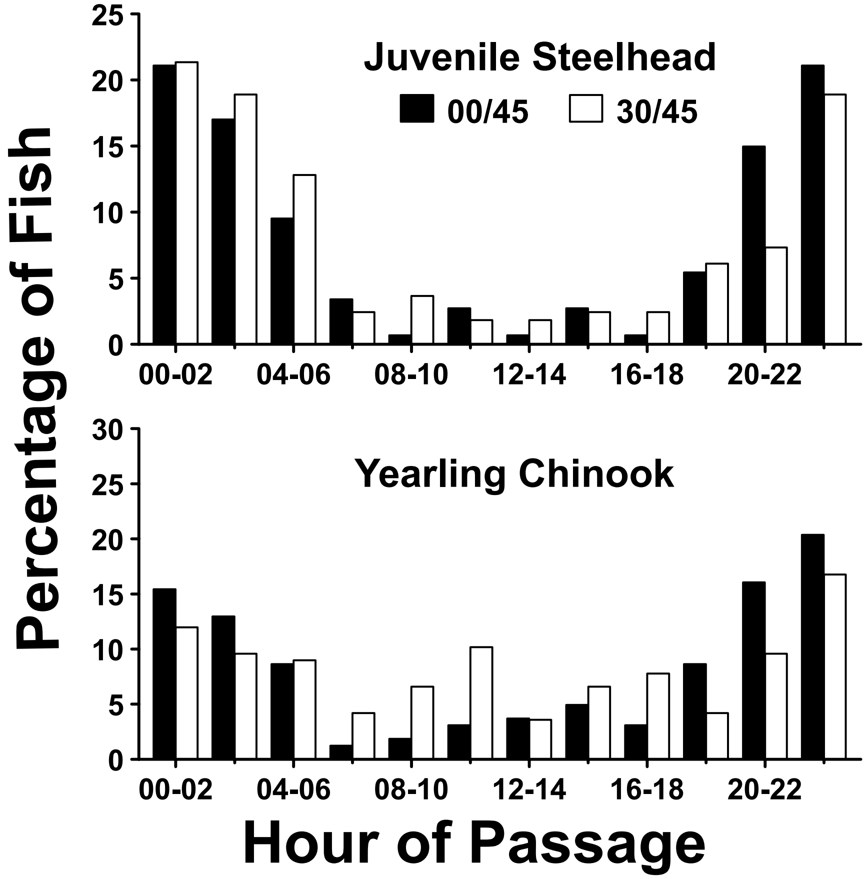

Figure 5. Diel distribution of radio-tagged juvenile steelhead and yearling chinook salmon passage among 2-h time intervals during two spill treatments at John Day Dam, spring 1999. Spill treatments: 00/45=0% day and 45% night spill; 30/45=30% day and 45% night spill. Sample size: juvenile steelhead 00/45=147, 30/45=164; yearling chinook 00/45=162, 30/45=167.

Fish and Spill Passage Efficiency

Neither juvenile steelhead nor yearling chinook salmon FPE estimates differed significantly between the 00/45 and 30/45 spill treatments (Table 4). Juvenile steelhead FPE (blocks 1-3 pooled) was 94% during the 00/45 treatment and 90% during the 30/45 treatment, whereas yearling chinook salmon FPE was 82 and 87%. Juvenile steelhead FPE was significantly greater than yearling chinook salmon FPE during the 00/45 treatment, but we could not detect a difference during the 30/45 treatment, although juvenile steelhead FPE was higher

(Blocks 1-3 pooled, Fisher Exact tests, $P<0.001$ and 0.26, respectively). The pooled-species FPE was 88% during the 00/45 treatment and 89% during the 30/45 treatment (Table 4). However, since the number of juvenile steelhead and yearling chinook in the sample are about equal, these estimates do not necessarily represent what might be obtained for a run-of-river species mix. No significant statistical difference could be discerned in FPE of the pooled species during the two spill treatments ($P=0.80$).

Juvenile steelhead SPE did not significantly differ between treatments, but yearling chinook salmon SPE was significantly greater during the 30/45 treatment than the 00/45 treatment (blocks 1-3 pooled; Table 5). Juvenile steelhead SPE was 45 and 53% during 00/45 and 30/45 treatments, respectively, whereas yearling chinook salmon SPE was 53 and 66%. Estimates of SPE did not differ statistically between species during the 00/45 treatment, but the yearling chinook salmon SPE estimate was 8% higher (Fisher Exact test, blocks 1-3 pooled, $P=0.07$; Table 5). Yearling chinook salmon SPE during the 30/45 treatment was significantly greater than juvenile steelhead SPE (Fisher Exact test, $P=0.001$). Spill passage efficiency of the pooled species was 49% during the 00/45 treatment and 59% during the 30/45 treatment (Table 5). In contrast to the combined FPE estimates, SPE of the pooled species was significantly higher during the 30/45 treatment than the 00/45 treatment ($P=0.01$; Table 5). As discussed above, however, these estimates do not necessarily represent what might be obtained for a run-of-river mix of the two species.

Table 4. Estimates ($p_{00/45}$ and $p_{30/45}$) of juvenile steelhead (STH), yearling chinook salmon (CH1), and pooled-species (ALL) fish passage efficiency (FPE) during two spill treatments at John Day Dam, spring 1999. Spill treatments: 00/45=0% day spill, 45% night spill; 30/45=30% day spill, 45% night spill. Day spill levels occurred between 0600-1859 h and night spill levels

occurred between 1900-0559 h. CI=confidence interval. N=sample size. Significant differences (*) in FPE between the spill treatments were evaluated using the Fisher Exact test (α=0.05).

		Spill Treatment							
		00/45			30/45			(HO:$p_{00/45} = p_{30/45}$)	
	Block	$p_{00/45}$	95% CI	N	$p_{30/45}$	95% CI	N	P	Power
STH	1	96.1	86.5-99.5	51	88.0	75.7-95.5	50	0.16	0.32
	2	94.4	81.3-99.3	36	89.5	78.5-96.0	57	0.48	0.11
	3	92.2	81.1-97.8	51	93.9	83.1-98.7	49	1.00	0.06
	Pooled	94.2	88.9-97.5	138	90.4	84.6-94.5	156	0.28	0.22
CH1	1	82.7	69.7-91.8	52	86.7	73.2-94.9	45	0.78	0.08
	2	75.0	61.6-85.6	56	81.0	68.6-90.1	58	0.50	0.12
	3	91.3	79.2-97.6	46	94.7	85.4-98.9	57	0.70	0.11
	Pooled	82.5	75.5-88.1	154	87.5	81.4-92.2	160	0.27	0.24
ALL	1	89.3	81.7-94.5	103	87.4	79.0-93.3	95	0.82	0.07
	2	82.6	73.3-89.7	92	85.2	77.4-91.1	115	0.70	0.08
	3	91.8	84.4-96.4	97	94.3	88.1-97.9	106	0.58	0.11
	Pooled	88.0	83.7-91.5	292	88.9	84.9-92.2	316	0.80	0.06

Table 5. Estimates ($p_{00/45}$ and $p_{30/45}$) of juvenile steelhead (STH), yearling chinook salmon (CH1), and pooled-species (ALL) spill passage efficiency (SPE) during two spill treatments at John Day Dam, spring 1999. Spill treatments: 00/45=0% day spill, 45% night spill; 30/45=30% day spill, 45% night spill. Day spill levels occurred between 0600-1859 h and night spill levels occurred between 1900-0559 h. CI=confidence interval. N=sample size. Significant differences (*) in FPE between the spill treatments were evaluated using the Fisher Exact test (α=0.05).

		Spill Treatment							
		00/45			30/45			(HO:$p_{00/45} = p_{30/45}$)	
	Block	$p_{00/45}$	95% CI	N	$p_{30/45}$	95% CI	N	P	Power
STH	1	45.1	31.1-59.7	51	44.0	30.0-58.7	50	1.00	0.05
	2	38.9	23.1-56.5	36	56.1	42.4-69.3	57	0.14	0.36
	3	49.0	34.8-63.4	51	57.1	42.2-71.2	49	0.43	0.13

	Pooled	44.9	36.5-53.6	138	52.6	44.4-60.6	156	0.20	0.26
CH1	1	48.1	34.0-62.4	52	66.7	51.1-80.0	45	0.10	0.45
	2	46.4	33.0-60.3	56	62.1	48.4-74.5	58	0.13	0.39
	3	65.2	49.8-78.6	46	68.4	54.8-80.1	57	0.83	0.06
	Pooled	52.6	44.4-60.7	154	65.6	57.7-72.9	160	0.02*	0.65
ALL	1	46.6	36.7-56.7	103	54.7	44.2-65.0	95	0.26	0.21
	2	43.5	33.2-54.2	92	59.1	49.6-68.2	115	0.04*	0.61
	3	56.7	46.3-66.7	97	63.2	53.3-72.4	106	0.39	0.16
	Pooled	49.0	43.1-54.9	292	59.2	53.5-64.6	316	0.01*	0.71

Our ability to statistically detect differences in FPE and SPE between spill treatments was dependent on the magnitude of the difference between the passage estimates and the sample size. Statistical power increases as the sample size and the difference between the proportions being compared get larger. Hence, the strongest comparisons are those where the data have been pooled and the differences between FPE and SPE estimates are the greatest (Table 4 and 5). In the case of juvenile steelhead and yearling chinook salmon FPE, where the differences in FPE estimates during the two spill treatments were less than or equal to 5% (blocks 1-3 pooled; Table 4), the statistical power was low and the probability of statistically detecting such a difference was beyond the scope and intent of the present study. In contrast, the probability that we would be able to detect true differences in SPE estimates of yearling chinook salmon was much higher (Table 5). The powers of the FPE comparisons are lower than the corresponding SPE comparisons with equal sample size because differences between the two spills were more pronounced in SPE than FPE. Exclusion of the fourth block of data from these comparisons reduced our power to detect differences in FPE and SPE, but probably did not adversely affect our conclusions concerning differences in FPE because these differences were relatively small.

Given a larger sample size of juvenile steelhead, however, we may have found a statistically significant difference in SPE between treatments, as was the case for the yearling chinook salmon (Table 5).

Effects of Species-Specific Passage Behavior on FPE and SPE

Potential differences in FPE estimates between spill treatments were reduced by species-specific responses to diel dam operations at the time of arrival. Differences in juvenile steelhead FPE estimates between treatments were minimized by the fact that fish arriving during 0 and 30% day spill conditions generally delayed passage until evening. Because of this behavior, 87% of the juvenile steelhead passed the dam during 45% night spill. During this spill period, 51.2% of the fish passed through the spillway, 42.6% passed through the JBS, and 6.2% passed through the turbines (Figure 6). Few juvenile steelhead passed during 30% day spill (N=23), but the percentages of fish passing via the spillway and powerhouse were similar to those passing at night, indicating that spill effectiveness was less during 45% night spill (1.1:1) than during 30% day spill (1.6:1). Fish guidance efficiency of juvenile steelhead that passed at night and during 0% daytime spill was higher than during 30% day spill (87.2, 85.0, and 58.3%, respectively).

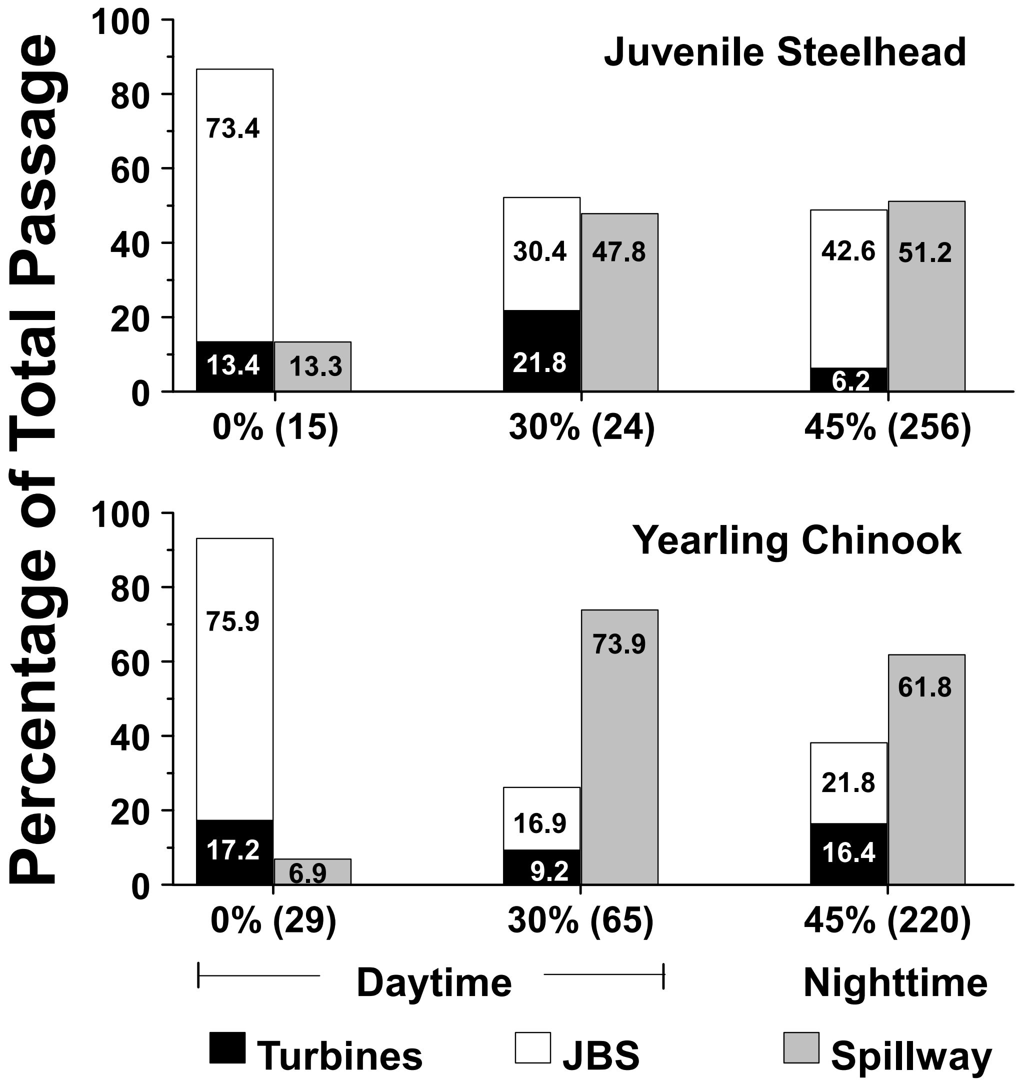

Figure 6. Percentage of radio-tagged juvenile steelhead and yearling chinook salmon at John Day Dam passing through the powerhouse (guided and unguided) at 0 and 30% day spill and 45% night spill, spring 1999. Specific passage percentages for each area are shown on the bars. During 0% spill there were small amounts of spill through which some fish passed. JBS=juvenile fish bypass system. Sample sizes are in parentheses.

Potential differences in yearling chinook salmon estimates were also affected by passage delays during 0% spill. Due to these delays, 73% of the fish arriving during the 00/45 treatment passed at night. Sixty-two percent of the fish passing during 45% night spill passed through the spillway, 22% passed through the JBS, and 16% passed through the turbines. Yearling chinook salmon arriving during 30% day spill were more likely to pass during this spill condition than juvenile steelhead and 75% of the fish arriving during this condition passed before the night spill. Of the fish passing during the 30% spill, 73.9% passed through the spillway, 16.9% passed through the JBS, and 9.2% passed through the turbines (Figure 6). These data indicate that FPE of yearling chinook salmon was higher during 30% day spill than during 45% night spill (91 vs. 84%); due largely to increased spill effectiveness during the day (2.4 vs. 1.4). The tendency of yearling chinook to pass readily through the spillway during 30% day spill resulted in significant differences in SPE between treatments. Fish guidance efficiency was higher during 0 and 30% day spill (81 and 65%, respectively) than during 45% night spill (57%).

We caution that some groups represented in Figure 6 have very small sample sizes due to the predominance of night passage and our discussion of this data is intended to identify potential trends in juvenile steelhead and yearling chinook salmon passage behavior during the dam-operating conditions observed in 1999. These specific inferences are not based on statistical comparison and probabilities of their likelihood have not been calculated. As such, they are of a speculative nature and may best serve as hypotheses for more rigorous testing in the future.

Acknowledgments

We thank Marvin Shutters, Rock Peters, Miro Zyndol, and other COE personnel for their efforts in managing our contract and assisting in planning and executing this research. This work would not have been accomplished without the field efforts and technical assistance of Rip Shively, Richard Case, Cari Clements, Ken Gates, Amanda Harrison, and Russel Perry. Many thanks go to Rick Martinson of the National Marine Fisheries Service and his staff at John Day Dam for collecting and holding fish for this study.

References

Adams, N.S., D.W. Rondorf, S.D. Evans, J.E. Kelly, and R.W. Perry. 1998. Effects of surgically and gastrically implanted radio transmitters on swimming performance and predator avoidance of juvenile chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 55: 781-787.

COE (U.S. Army Corps of Engineers), 1999. River Data. ONLINE. U.S. Army Corps of Engineers, Portland, Oregon, USA. Available: http://www.nwd-wc.usace.army.mil/-TMT/tdg_data/months.html [accessed June, 1999].

Hensleigh, J.E., R.S. Shively, H.C. Hansel, J.M. Hardiman, G.S. Holmberg, B.D. Liedtke, T.L. Martinelli, R.E. Wardell, R.H. Wertheimer, and T.P. Poe. 1999. Movement, distribution and behavior of radio-tagged juvenile chinook salmon and steelhead in John Day, The Dalles and Bonneville dam forebays, 1997. Annual report of research, U.S. Army Corps of Engineers, Portland District, Portland, Oregon, USA.

Holmberg, G.S., R.S. Shively, H.C. Hansel, T.L. Martinelli, M.B. Sheer, J.M. Hardiman, B.D. Liedtke, L.S. Blythe, and T.P. Poe. 1998. Movement, distribution, and behavior of radio-tagged juvenile chinook salmon in John Day, The Dalles, and Bonneville forebays, 1996. Annual report of research, U.S. Army Corps of Engineers, Portland District, Portland, Oregon, USA.

NMFS (National Marine Fisheries Service). 1998. Supplemental biological opinion: operation of the federal Columbia River power system including the smolt monitoring program and the juvenile fish transportation program. A supplement to the Biological Opinion signed on March 2, 1995 for the same projects. Endangered Species Act-Section 7 Consultation, National Marine Fisheries Service, Northwest Region, Seattle, Washington, USA.

Sheer, M.B., G.S. Holmberg, R.S. Shively, T.P. King, C.N. Frost, H.C. Hansel, T.M. Martinelli, and T.P. Poe. 1997. Movement, distribution, and passage behavior of radio-tagged juvenile chinook salmon in John Day and The Dalles Dam forebays, 1995. Annual report of research, U.S. Army Corps of Engineers, Portland District, Portland, Oregon, USA.

Whitney, R.R., L.D. Calvin, M.W. Erho, Jr., C.C. Coutant. 1997. Downstream passage for salmon at hydroelectric projects in the Columbia River Basin: development, installation, and evaluation. Prepared for the Northwest Power Planning Council, Portland, Oregon, USA. #97-15.

Zar, J.H. 1996. Biostatistical Analysis, third edition. Prentice-Hall, Inc. Englewood Cliffs, New Jersey, USA.

Appendix A

Appendix A1. Summary of the number of radio-tagged juvenile steelhead released (N) at Rock Creek during spring, 1999, and mean, standard deviation (SD), and range of the fork length (mm) and weight (g).

			Fork length (mm)			Weight (g)		
Date	Hour	N	Mean	SD	Range	Mean	SD	Range
05/06	0000	14	224.5	34.6	128-270	110.0	34.3	68.0-177.8
05/07	1300	15	224.0	19.3	185-265	97.8	26.6	56.0-169.6
05/07	2000	15	216.9	17.7	180-247	95.7	28.9	67.7-138.0
05/08	0900	15	215.9	29.9	164-258	-	-	-
05/09	2000	14	226.6	21.2	182-263	99.4	27.3	48.8-149.8
05/10	0800	12	228.6	24.2	191-287	109.6	43.3	64.4-227.5
05/10	2000	13	220.2	14.8	191-243	93.4	16.7	64.3-119.3
05/11	1100	19	219.9	19.7	191-273	94.1	26.0	56.5-170.4
05/12	2000	14	213.2	26.4	178-258	86.1	34.2	47.6-150.5
05/13	0800	11	213.9	19.8	177-246	83.1	21.1	44.0-111.5
05/13	2000	13	212.6	24.4	176-260	82.8	30.5	44.5-153.8
05/14	0800	19	213.2	24.8	174-275	85.4	34.7	28.8-186.4
05/15	2000	13	213.0	20.1	194-256	86.6	26.7	59.7-138.5
05/16	0800	9	211.6	50.4	117-286	95.8	56.6	45.8-198.1
05/16	2000	12	226.5	27.3	168-265	107.2	31.3	69.2-163.2
05/17	0800	12	205.6	14.6	183-234	71.5	22.3	45.8-134.4
05/18	2000	16	209.4	19.3	174-243	78.6	22.9	46.4-131.1
05/19	0900	12	222.2	29.7	182-274	98.2	39.7	55.9-179.4
05/19	2000	10	214.0	19.6	180-242	79.0	20.1	52.5-120.7
05/20	0800	21	217.7	25.4	181-275	90.2	35.0	47.0-176.7
05/21	0800	9	217.9	22.1	192-252	87.6	28.7	57.7-131.1
05/21	2000	10	202.9	20.2	167-236	67.4	19.7	35.6-103.8
05/22	2000	20	208.5	20.7	179-262	77.6	25.9	41.7-155.6
05/23	0800	18	206.1	21.1	174-256	72.4	25.2	43.5-138.2
05/24	2000	21	211.8	25.1	173-278	82.0	30.9	44.6-161.2
05/25	0800	14	206.3	19.4	182-250	74.4	23.5	52.0-132.0
05/25	2000	13	208.8	15.8	185-246	76.9	20.3	48.2-127.3
05/26	0800	26	207.8	25.7	163-276	77.3	36.4	35.8-197.5
05/27	2000	24	200.4	10.3	182-221	66.6	9.8	49.0-88.2
05/28	0800	12	206.5	21.2	181-267	73.0	25.8	47.6-148.7
05/28	2000	12	212.0	18.4	186-252	81.6	27.2	53.7-147.0
05/29	0800	21	222.1	24.0	187-258	93.2	31.0	57.5-145.6

Overall		479	214.0	23.6	117-287	85.5	30.7	28.8-227.5

Appendix A2. Summary of the number of radio-tagged yearling chinook salmon released (N) at Rock Creek during spring, 1999, and mean, standard deviation (SD), and range of the fork length (mm) and weight (g).

			Fork length (mm)			Weight (g)		
Date	Hour	N	Mean	SD	Range	Mean	SD	Range
05/06	0000	13	167.5	33.3	125-222	54.1	35.2	19.9-116.8
05/07	1300	15	152.3	22.1	123-195	40.3	18.3	18.5-78.4
05/07	2000	14	167.6	25.8	139-213	48.9	23.3	25.2-105.2
05/08	0900	15	174.2	28.9	142-222	-	-	-
05/09	2000	15	155.9	21.2	131-191	41.3	17.4	23.6-72.3
05/10	0800	12	165.9	21.0	146-208	46.3	16.7	31.0-77.6
05/10	2000	13	186.5	30.6	142-228	69.0	37.3	27.5-131.1
05/11	1100	20	184.9	21.6	141-220	69.4	25.3	27.1-112.7
05/12	2000	20	167.0	32.8	126-233	53.9	36.8	21.2-146.5
05/13	0800	10	178.7	30.5	136-223	60.8	31.0	25.6-113.8
05/13	2000	10	171.4	40.6	129-246	60.3	50.5	20.4-167.6
05/14	0800	20	166.5	22.2	140-235	49.3	27.4	26.8-150.6
05/15	2000	19	177.7	25.9	142-215	59.6	25.8	26.3-100.1
05/16	0800	10	165.7	23.3	141-216	46.6	20.2	25.8-87.1
05/16	2000	10	158.6	48.2	133-214	56.6	19.4	32.6-98.6
05/17	0800	21	170.0	18.5	135-230	50.2	19.7	22.5-125.4
05/18	2000	19	173.4	20.4	135-216	52.2	19.5	21.9-103.5
05/19	0900	10	151.8	8.1	145-167	33.6	7.3	21.0-45.4
05/19	2000	10	161.0	16.7	135-180	41.0	12.8	21.7-54.7
05/20	0800	20	163.4	20.2	137-201	43.3	16.2	25.6-74.8
05/21	0800	7	157.9	17.6	137-189	40.6	15.1	23.2-66.1
05/21	2000	9	156.9	17.1	135-190	38.1	15.1	23.5-70.8
05/22	2000	19	155.9	31.2	148-197	40.6	14.9	23.1-76.5
05/23	0800	21	160.7	15.4	132-194	40.3	12.4	20.3-69.3
05/24	2000	21	159.9	17.7	135-193	39.7	14.2	22.3-71.2
05/25	0800	10	162.9	13.1	134-176	40.0	9.1	21.2-49.6
05/25	2000	10	180.1	23.5	151-220	56.4	22.8	31.2-97.1
05/26	0800	24	162.7	20.2	134-210	42.0	18.0	22.3-92.9
05/27	2000	21	161.1	22.9	134-211	40.0	16.5	21.7-74.5
05/28	0800	12	166.7	22.8	135-220	44.3	24.2	22.2-108.8
05/28	2000	12	163.0	21.3	135-198	41.2	15.7	23.2-65.4
05/29	0800	7	156.1	17.4	140-181	35.2	12.2	24.8-54.3

Overall	469	166.0	25.1	123-246	47.8	23.7	18.5-167.6